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COMPARISON OF C-BAND RADAR AND DOPPLER GEOCEIVER ACCURACIES IN --ETC(U)

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COMPARISON OF C-BAND RADAR AND DOPPLER GEOCEIVER ACCURACIES IN ORBIT DETERMINATION

by
CAROL G. BRANCH
Strategic Systems Department

NOVEMBER 1978

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A study is made herein of the relative consistency of C-band and Doppler station navigations with respect to a Doppler-derived orbit. The procedure, results, error analyses, and accuracy criteria are included. It is concluded that C-band radar tracking data are not an adequate substitute for Doppler geoceiver data in computing orbits of satellites when precise altitudes are required for satellite altimeter applications.		

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FOREWORD

Currently, Doppler geoceivers are the primary source of tracking data used in orbit determination at the Naval Surface Weapons Center (NSWC). Consideration has been given to supplementing these stations with selected sites from the worldwide C-band radar network. This report examines the relative consistency and compatibility of the two data types.

Mr. Patrick J. Fell formulated the changes in CELEST required by this study. In addition, he supervised the initial program checkout. Mrs. Treva Burgess accomplished the actual coding and computer implementation. Mr. Alfred Buonaguro acted as a consultant in evaluating the orbit and interpreting the results.

The work was reviewed by Mr. Richard J. Anderle, Head, Astronautics and Geodesy Division, Strategic Systems Department.

Released by:

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ABBREVIATIONS/DEFINITIONS

e	Eccentricity of elliptical orbit
NAD	North American Datum
NASA/WFC	National Aeronautics and Space Administration/Wallops Flight Center
NSWC	Naval Surface Weapons Center
0-C	Observed minus computed
S/N	Signal-to-noise ratio
(Bias-Reduced)	Measure of residuals with bias solution applied
(Old)	Measure of current raw residuals
(Predicted)	Measure of residuals with bias and orbit solutions applied
TCA	Time of closest approach
σ	Standard deviation (sigma)

INTRODUCTION

In the sphere of orbit determination, the quality and quantity of tracking data are extremely important. With this in mind, the GEOS-III satellite was equipped with a Doppler radio beacon, two C-band radar transponders (one coherent and one noncoherent), and laser retro-reflectors. Worldwide ground-based tracking nets are operating in support of each of these instruments. This simultaneous data sampling provides the opportunity to evaluate system accuracies and calibration, as well as to determine cross-system compatibility.

At NSWC, Doppler is the primary tracking data used in orbit determination. C-band radar, however, was considered as a substitution for Doppler data at some sites for use in computing the orbit of the GEOS-III satellite. It was hoped that this increase in the quantity of data available could be attained without a sacrifice in quality.

Hence, the purpose of this particular study is to determine if C-band radar measurements are of sufficient accuracy to be used in place of Doppler measurements at selected sites. The knowledge gained in this effort could be used to improve satellite ephemerides and, thus, to obtain a more exact radar altimeter position.

PROCEDURE

GENERAL

C-band radar data from selected sites are preprocessed and put in a format compatible with the CELEST orbit determination program. Using a precise, Doppler-derived GEOS-III trajectory, C-band pass matrices were formed and merged with existing Doppler pass matrices.

The GEOS-III orbit was computed using Doppler data alone. C-band and Doppler residuals with respect to this orbit were then compared. Figure 1 shows a flowchart for the analysis of the data, which includes the respective sections of CELEST used and depicts the processing of both Doppler and radar measurements.

PROCEDURE

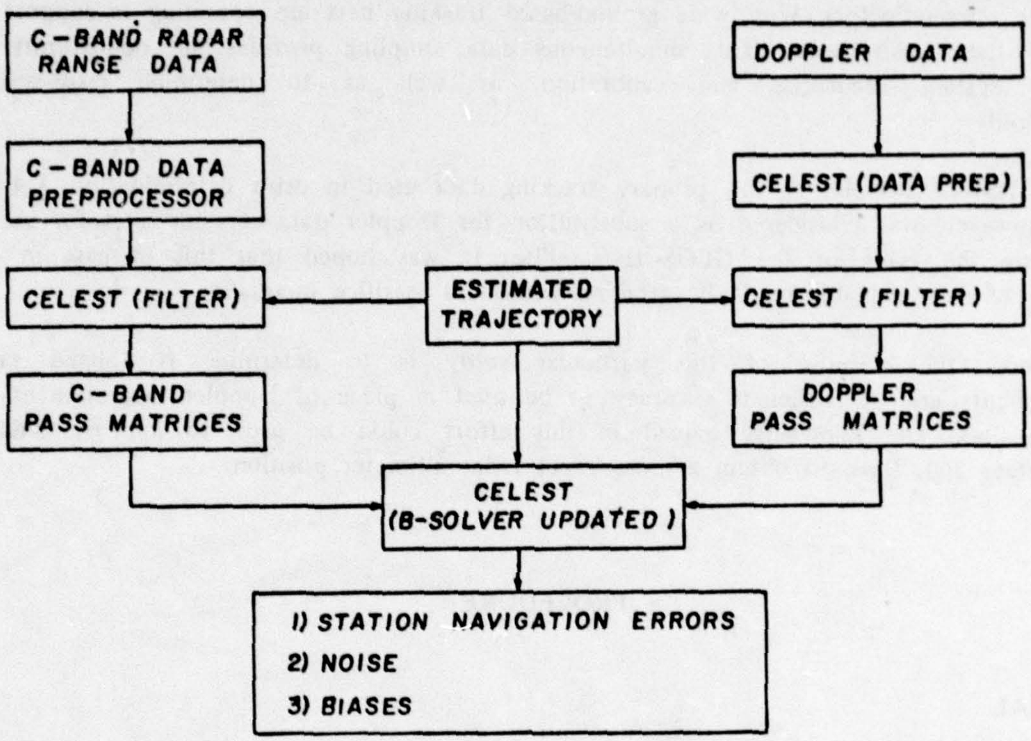

Figure 1. Data Processing Flowchart

DETERMINATION OF STATION COORDINATES

The geographical coordinates of the C-band stations used in this study were only available in the North American Datum (NAD) or some other local system (Reference 1). However, NSWC used the 9D Datum. A direct conversion from NAD to 9D coordinates would incorporate all the network-wide discrepancies between the two systems. Derived for 47 stations in the coterminous United States, the mean translation induced by this method is 5.58 m (Reference 2). In order to avoid this source of error, a different method of conversion was used.

Coordinates for the geoceiver site are available in both the 9D and the local system. Thus, for the collocated C-band sites, the following equations were used:

$$\lambda^{R}_{9D} = \lambda^{G}_{9D} + (\lambda^{R}_{NAD} - \lambda^{G}_{NAD})$$

$$\phi^{R}_{9D} = \phi^{G}_{9D} + (\phi^{R}_{NAD} - \phi^{G}_{NAD})$$

$$W^{R}_{9D,SPH} = H^{G}_{9D,SPH} + (H^{R}_{NAD,MSL} - H^{G}_{NAD,MSL})$$

where

λ = east longitude
ϕ = north latitude
H = height
G = geoceiver
R = radar
SPH = spheroid
MSL = mean sea level

C-band stations #4840 and #4860 were solved for in this manner, using coordinates of the collocated geoceiver #30369. As a result, these locations were accurately determined.

There were no collocated Doppler stations for the other sites considered in this analysis. In fact, the closest geoceivers were from 60 to 120 mi away; thus, even when using the new method, large errors could be incurred. Hence, the results obtained for these stations indicated large navigation discrepancies between C-band and Doppler. Because of this problem, these particular results were omitted from the report.

Table 1 presents the original NAD coordinates for the C-band sites and their derived 9D coordinates. The NAD and 9D geoceiver coordinates are also included.

Table 1. Station Coordinates

NAD STATION COORDINATES

Type	Station #	East Longitude	North Latitude	MSL Height (m)
C-Band Radar	4840	284.514549	37.841220	12.4
	4860	284.490343	37.860141	15.0
Geoceiver	30369	284.489858	37.859679	7.2

9D STATION COORDINATES

Type	Station #	East Longitude	North Latitude	SPH Height (m)
C-Band Radar	4840	284.514691	37.841322	-33.0
	4860	284.490485	37.860243	-30.5
Geoceiver	00111	284.103155	39.163371	102.4
	03069	284.489999	37.859789	-38.2

C-BAND DATA PREPROCESSING

The C-band radar range data (Type 21) received from NASA/Wallops Flight Center were corrected for individual radar calibration errors and transponder delay effects. However, ionospheric and tropospheric refraction corrections had not been applied.

A data preprocessor was formulated that screens the data and thereby deletes any observations in obvious error. The data are then grouped into passes. If necessary, the number of points is reduced (≤ 200) by extracting observations at discrete intervals. The measurements are not averaged or interpolated.

POINT FILTERING

The preprocessed C-band observations, in the format of the data prep file, are then input in the Filter section of CELEST, along with an estimated perturbed trajectory. For each individual pass, Filter determines the good and bad points. The final ***weights*** are then assigned, and the least-square normal equations are formed using only the good points. These equations are simply the partial derivatives of the position and velocity with respect to the various orbit parameters, the drag scaling factor, and the tropospheric refraction and range biases.

ORBIT SOLUTION

The C-band pass matrices produced by Filter are merged with the corresponding Doppler pass matrices. The resultant file, along with an estimated trajectory, is input to the B-Solver (matrix combiner-solver) module of CELEST. In this case, the long-arc (two day) fit was implemented.

This modified version of B-Solver performs a position refinement only on the basis of the reduced geoceiver observations. The ***good*** Doppler pass matrices are added together to form a matrix of arc normal equations, which is then solved for improvements in the parameters of the fit. These include the six orbit constants, a drag scaling factor, and, for each pass, a refraction bias. In addition, an individual frequency or range bias is computed for the Doppler and C-band passes, respectively.

After each improvement cycle, station navigation errors are derived for the individual passes. This diagnostic procedure will be discussed later. At the end of the last cycle, the bias solution for each pass is computed, along with the mean orbital elements and filtered noise for the Doppler passes.

STATION NAVIGATION SOLUTION

This diagnoistic procedure is executed after each orbit improvement. The O-C is obtained for each point in the pass, and the station position, which minimizes the weighted squares of these residuals, is determined. The ***navigation*** is simply the difference between the ***improved*** and actual positions. Since the coordinates of the station are assumed to be well-known, any navigation can be attributed to error in the ephemeris.

The orbit parameters are well-determined only within the confines of the orbit plane. Therefore, the cross-track (out-of-plane) component of the navigation is weighted out of the solution. The results are output in the local $(\hat{\rho},\dot{\hat{\rho}})$ system, where $\hat{\rho}$ is the topocentric satellite position vector and $\dot{\hat{\rho}}$ is the component of the velocity vector with respect to the observer. Thus, $\hat{\rho}$ and $\dot{\hat{\rho}}$ are in the radial and tangential directions, respectively. The sigmas (standard deviations) of the two navigation components are obtained from the covariance matrix (Reference 3).

RESULTS

CRITERIA

The primary purpose of this study was to compare the station navigation errors of C-band radars and geoceivers simultaneously tracking GEOS-III. Since CELEST outputs these residuals in the local $(\hat{\rho},\dot{\hat{\rho}})$ frame, a truly accurate comparison can only be obtained for collocated sites.

Radar-calibrated data were received for days 182-203 of 1975. Although several C-band stations were operative, no collocated geoceivers were tracking the satellite during this time. Even the closest sites were from 60 to 130 mi apart.

Consideration was given to translating the navigation errors to a time-independent frame (i.e., inertial), which would have facilitated a more conclusive comparison of orbit residuals. However, the data can only determine the navigations accurately in two components. Hence, valid three-dimensional coordinates could not be obtained.

Since the velocity vector of the satellite does not change appreciably in a small time interval, the tangential unit vectors should be nearly equal for adjacent stations. The main error is incurred in the ρ coordinate. The elevation (measured from vertical) of the passes for the two sites usually agreed to within 5°. The maximum difference was 9.4°. By knowing the approximate altitude of the satellite and by studying the ground tracks, the radial navigation of one station was projected onto the radial component for the adjacent site. It was concluded that a significant discrepancy would not be incurred, even in the slant range component.

The Doppler-derived orbit was referenced to the electrical center of the Doppler antenna, while the C-band data were referenced to the phase center of the C-band coherent transponder. However, the antenna offsets in the x, y, and z axes were only 9.0, 21.9, and 8.9 in., respectively. Thus, the station navigation induced by this discrepancy would be negligible.

The only simultaneously operating Doppler site in the vicinity of Wallops Island was the TRANET station (#00111) in Howard County, Maryland. This geoceiver was approximately 130 mi distant. The standard error for the Doppler solution was required to be better than 3 m. Passes failing to meet this criterion were omitted from the study.

C-BAND STATION #4840: WALLOPS ISLAND

Tables 2 and 3 present the individual station navigations and the station navigation differences, respectively, for C-band radar #4840.

For the FPS-16 radar, the mean filtered noise (random error of the observation) was 1.39 m. This value seemed to be independent of both the elevation and the time of the pass. With a standard deviation of only 0.13 m, the magnitude varied only slightly from pass to pass. The 0-C plots indicated that the error was fairly random. Only two passes (#1 and #11) showed a significant signal in the data.

The average tropospheric refraction bias computed in B-Solver for the C-band and Doppler passes were 10 and 7 percent, respectively. The C-band range bias averaged 2.6 m. For the Doppler, the frequency bias was approximately five parts/million.

A comparison of the radar and Doppler radial navigations revealed an average difference of 3.3 m. The C-band sigma for this value ($\simeq$ 1.8 m) was generally much larger than the Doppler sigma ($\simeq$ 0.4 m). This reflects a greater random error in the C-band station navigations.

The slant range difference exceeded 5 m in only three cases. For pass #2, for example, there was a 6.8-m residual. The Doppler standard deviation for this pass, however, was relatively large (0.7 m), which may have contributed to the error.

The Doppler sigma for pass #7 was even larger (0.9 m), as was the noise level (0.14 m). This indicates that the Doppler data were slightly below par. In addition, the tropospheric refraction bias for both C-band and Doppler was greater than 30 percent.

The 7.8-m difference in pass #11 was probably the result of a bad radar pass. The C-band sigma was over 4 m, which is far above average.

For the tangential navigation component, the agreement was closer. The mean difference was only 1.6 m. In fact, the 3-m level was exceeded in only one case (pass #7). The tangential Doppler sigma was about 0.9 m.

It may be noted that the C-band along-track sigma was consistently small. The value was probably minimized by the sheer abundance of radar observations. Compared with a Doppler sample of 20 sec, the radar sample interval is approximately 5 sec. Experiment has shown that the standard error of correlated range data is approximately one-fifth that of uncorrelated range-difference data. In addition, the filtered noise for the C-band was 1.4 m, while that of the Doppler was approximately 0.06 m. Therefore, the C-band sigma should be 0.2 ($\sqrt{0.06/1.4}$) again that of the Doppler sigma. Another contributing factor was that the C-band frequency bias was not derived. By decreasing the number of parameters, you decrease the sigma.

Table 2. Individual Station Navigations:
C-Band Radar #4840

RADAR TYPE: FPS-16 COMPARISON DOPPLER: 00111

PASS #	FIT INTERVAL (DAYS)	C-BAND TCA		BIAS SOLUTION				STATION NAVIGATIONS (M)							
				C-BAND		DOPPLER		RADIAL				TANGENTIAL			
		DAY	SEC.	TROPOS. REFRAC. (%)	RANGE (M)	TROPOS. REFRAC. (%)	FREQ. (HZ/MHZ)	C-BAND	DOPPLER	C-BAND σ	DOPPLER σ	C-BAND	DOPPLER	C-BAND σ	DOPPLER σ
1	184-	184	27970	15.	-1.	13.	-.006	-3.2	-6.5	1.3	.2	-.6	.5	.2	.2
2	185	184	62968	9.	-2.	4.	-.006	6.0	-.8	2.9	.7	1.5	1.1	.3	.7
3	188-	189	23668	5.	.4	2.	-.005	-1.1	-2.1	1.6	.4	7.1	9.2	.2	.7
4	189	189	29592	1.	-2.	1.	-.005	-2.8	-3.9	1.1	.4	3.4	5.0	.2	.3
5		189	58654	2.	-4.	7.	-.005	.8	-2.7	.9	.5	-3.6	-2.3	.2	.4
6	190-	190	57800	15.	-4.	6.	-.005	.8	-.8	1.3	.3	.4	2.1	.2	.3
7	191	191	62852	33.	-6.	35.	-.005	8.2	-.1	.9	.8	2.4	-3.5	.2	.9
8		193	26151	5.	2.	7.	-.005	-.8	.1	1.1	.6	5.8	6.5	.2	.6
9	192-	193	32067	.3	-1.	9.	-.005	-3.1	-5.8	1.4	.4	4.5	4.1	.2	.3
10	193	193	61131	26.	-.5	3.	-.005	1.8	.9	.9	.2	-2.0	-3.5	.1	.1
11		193	67070	3.	1.	3.	-.005	3.9	-3.9	4.2	.5	-2.4	-1.9	.3	.8
12	194-	195	24414	21.	-3.	6.	-.005	4.7	5.7	4.1	.8	-4.9	-4.2	.3	.9
13	195	195	59422	10.	-7.	3.	-.005	-.5	4.0	1.8	.2	3.0	5.4	.3	.2
14	202-	203	35311	8.	-2.	.6	-.005	-.6	-4.0	1.0	.2	-.1	.8	.2	.2
15	203	203	64372	.1	-3.	8.	-.005	.8	-1.7	1.0	.2	-5.5	-3.5	.2	.2
16		203	70301	5.	3.	2.	-.005	-1.7	-5.2	2.7	.2	-3.7	-1.8	3	.2

Table 3. Station Navigation Difference:
C-Band Radar #4840

RADAR TYPE : FPS-16 COMPARISON DOPPLER : 00111

PASS #	FIT INTERVAL (DAYS)	TCA OF PASS			ELEVATION		FILTERED NOISE (M)		STATION NAVIGATIONS (M)					
									RADIAL			TANGENTIAL		
		DAY	C-BAND	DOPPLER	C-BAND	DOP-PLER	C-BAND	DOPPLER	DIFFERENCE	C-BAND σ	DOPPLER σ	DIFFERENCE	C-BAND σ	DOPPLER σ
1	184-	184	27970.	27966	39.9	48.0	1.54	.05	3.3	1.3	.2	-1.1	.2	.2
2	185	184	62968.	62997.	209	22.0	1.56	.08	6.8	2.9	.7	.4	.3	.7
3	188-	189	23668.	23656.	29.7	25.2	1.41	.06	1.0	1.6	.4	-2.1	.2	.7
4	189	189	29592.	29587.	45.5	54.9	1.42	.07	1.1	1.1	.4	-1.6	.2	.3
5		189	58654.	58682.	53.4	53.4	1.31	.08	3.5	.9	.5	-1.3	.2	.4
6	190-	190	57800.	57828.	37.3	37.7	1.33	.06	1.6	1.3	.3	-1.7	.2	.3
7	191	191	62852.	62880.	55.9	57.6	1.34	.14	8.3	.9	.8	5.9	.2	.9
8		193	26151.	26140.	38.4	32.4	1.15	.09	-.9	1.1	.6	-.7	.2	.6
9	192-	193	32067.	32063.	36.6	44.0	1.49	.08	2.7	1.4	.4	.4	.2	.3
10	193	193	61131.	61159.	67.7	67.2	1.28	.03	.9	.9	.2	1.5	.1	.1
11	1	193	67070.	67098.	18.7	19.8	1.41	.04	7.8	4.2	-.5	-.5	.3	.8
12	194-	195	24414.	24400.	16.6	13.9	1.46	.05	-1.0	4.1	.8	.7	.3	.9
13	195	195	59422.	59450.	32.9	33.4	1.21	.04	-4.5	1.8	.2	-2.4	.3	.2
14	202-	203	35311.	35306.	47.5	57.4	1.29	.01	3.4	1.0	.2	-.9	.2	.2
15	203	203	64372.	64400.	51.0	51.1	1.41	.03	2.5	1.0	.2	-2.0	.2	.2
16		203	70301.	70329.	25.7	26.9	1.70	.03	3.5	2.7	.2	-1.9	.3	.2

C-BAND STATION #4860: WALLOPS ISLAND

Tables 4 and 5 present the individual station navigations and the station navigation differences, respectively, for C-band radar #4860.

For the FPQ-6 radar, the filtered noise was in the range of 1.3 m, which was approximately 25 times the level for the Doppler ($\simeq 0.05$ m). The O-C plots indicated that the observation errors were fairly random. A significant signal was present in only two cases. In pass #8, the filtered noise was 1 m, but the tropospheric refraction bias was very large ($\simeq 0.4$ m). Pass #13 also displayed a strong signal. However, the noise level, solution biases, and sigmas for the track did not indicate any major deviation from the norm.

The mean tropospheric refraction bias was 21 percent; however, the maximum value exceeded 60 percent. The corresponding average for the Doppler was six percent. In fact, the Doppler bias exceeded one percent in only one pass. The C-band range and Doppler frequency biases were both negligible.

In the radial component, the radar and geoceiver navigations differed by an average of 4.7 m. In fact, almost 50 percent of the passes had disparities of over 5 m. The maximum value was over 10 m for pass #9. However, the groundtrack indicated that the satellite went between the two stations. The identical C-band and Doppler TCAs emphasize the point. The absolute navigations for the radar and Doppler were -9.1 and 0.9 m, respectively. It is possible that the C-band data might have sensed a portion of the Doppler's out-of-plane component. In this case, the Doppler's corresponding navigation would have been weighted out of the solution.

The C-band radial standard error was about 3 m for the 13 passes, while that of the Doppler was approximately 0.7 m. Doppler passes #2 and #5, however, had sigmas exceeding 1 m. This error is still below the 3-m criterion for this study.

The agreement in the tangential component was on the level of 3.2 m. The standard deviations for the radar and Doppler were 0.65 and 0.52 m, respectively. The largest discrepancy (12.9 m) was for pass #2, in which the Doppler sigma was very large (1.2 m). In addition, the C-band noise level was almost 1.7 m.

The 5.7-m difference for pass #3 was probably caused by a bad radar track. This is implied by the 5.5-m C-band standard deviation. Almost all of the data for the first half of the pass was missing. With the exception of this case, the C-band tangential sigma was consistently smaller than the corresponding Doppler value.

Table 4. Individual Station Navigations:
C-Band Radar #4860

RADAR TYPE : FPQ-6 COMPARISON DOPPLER : 00111

PASS #	FIT INTERVAL (DAYS)	C-BAND TCA		BIAS SOLUTION				STATION NAVIGATIONS (M)							
				C-BAND		DOPPLER		RADIAL				TANGENTIAL			
		DAY	SEC.	TROPOS. REFRAC. (%)	RANGE (M)	TROPOS. REFRAC. (%)	FREQ. (HZ/MHZ)	C-BAND	DOPPLER	C-BAND σ	DOPPLER σ	C-BAND	DOPPLER	C-BAND σ	DOPPLER σ
1	188-	188	53633	5.	-5.	.2	-.005	-1.7	6.5	3.9	.6	-10.7	-6.4	.3	.8
2	189	188	65455	14.	-2.	3.	-.005	-4.8	-4.1	6.1	1.1	-1.5	11.4	.4	1.2
3	192-	192	27016	10.	-3.	.7	-.005	3.1	1.6	5.5	.3	7.0	1.3	5.5	.3
4	193	192	56102	21.	-2.	7.	-.005	-.7	6.7	2.9	.4	-5.0	-8.7	.2	.3
5		192	61990	31.	-2.	3.	-.005	3.5	3.1	.7	1.9	4.3	5.8	.1	.6
6	194-	194	60275	16.	-9.	5.	-.005	2.1	.8	1.2	.3	-4.3	-1.7	.2	.3
7	195	194	66201	5.	-.02	6.	-.005	1.7	-2.9	2.4	.4	-1.7	-.8	.3	.4
8	200-	200	31976	43.	-8.	2.	-.005	4.2	-2.5	.6	.9	-2.6	-.4	.1	.3
9	201	200	37859	3.	-1.	5.	-.005	-9.1	.9	3.6	.5	-.9	-.1	.3	.7
10		200	61045	23.	-5.	7.	-.005	-1.1	2.2	1.3	.3	.2	3.3	.2	.3
11	202-	202	59353	15.	-1.	1.	-.005	1.3	6.7	5.7	.5	-7.4	-6.0	.4	.6
12	203	202	65229	66.	-6.	43.	-.005	12.8	4.4	.8	.8	.2	2.1	.2	.5
13		202	71171	19.	-5.	.5	-.005	-3.3	.2	3.8	.5	2.2	3.3	.3	.5

Table 5. Station Navigation Differences:
C-Band Radar #4860

RADAR TYPE: FPQ-6 COMPARISON DOPPLER: 00111

PASS #	FIT INTERVAL (DAYS)	TCA OF PASS			ELEVATION		FILTERED NOISE (M)		STATION NAVIGATIONS (M)					
									RADIAL			TANGENTIAL		
		DAY	C-BAND	DOPPLER	C-BAND	DOP-PLER	C-BAND	DOPPLER	DIFFERENCE	C-BAND σ	DOPPLER σ	DIFFERENCE	C-BAND σ	DOPPLER σ
1	188-	188	53633.	53660.	16.5	17.2	1.16	.06	-8.2	3.9	.6	-4.3	.3	.8
2	189	188	65455.	65483.	15.8	16.8	1.68	.07	-.7	6.1	1.1	-12.9	.4	1.2
3	192-	192	27016.	27006.	57.8	48.4	1.21	.07	1.5	5.5	.3	5.7	5.5	.3
4	193	192	56102.	56130.	19.9	20.6	1.16	.04	-7.4	2.9	.4	3.7	.2	.3
5		192	61990.	62018.	83.4	84.7	1.00	.06	.4	.7	1.9	-1.5	.1	.6
6	194-	194	60275.	60303.	46.5	46.7	1.53	.07	1.3	1.2	.3	-2.6	.2	.3
7	195	194	66201.	66229.	28.6	29.8	1.73	.07	4.6	2.4	.4	-.9	.3	.4
8	200-	200	31976.	31969.	86.9	79.3	.99	.04	6.7	.6	.9	-2.2	.1	.3
9	201	200	37859.	37859.	18.2	21.9	1.39	.04	-10.0	3.6	.5	-.8	.3	.7
10		200	61045.	61073.	29.2	29.7	1.10	.03	-3.3	1.3	.3	-3.1	.2	.3
11	202-	202	59353.	59380.	15.9	16.6	1.67	.04	-5.4	5.7	.5	-1.4	.4	.6
12	203	202	65229.	65257.	74.4	73.8	1.44	.06	8.4	.8	.8	-1.9	.2	.5
13		202	71171.	71199.	16.8	17.7	1.31	.05	-3.5	3.8	.5	-1.1	.3	.5

SUMMARY

Of the two types of C-band equipment studied, the FPS-16 proved to be the more reliable. The average filtered noise for both radars was 1.3 to 1.4 m. However, the derived tropospheric refraction bias was more evident in the FPQ-6 passes. A comparison of the standard deviations indicated that the FPS-16 range observations were more consistent.

The station navigation solution for the FPS-16 was in closer agreement with that of the Doppler. In the radial component, the radar/Doppler difference had a mean of 3.3 m for the FPS-16. The FPQ-6, however, averaged 4.7 m. The mean tangential navigation difference for the FPQ-6 was 3.2 m. Even if pass #2 were disregarded (Doppler σ = 1.2 m), the average difference would still be 2.4 m. This is significantly larger than the 1.6-m level for the FPS-16.

In this study, the standard error for the Doppler had to be less than 3 m. The proposed criterion was a C-band/Doppler navigation agreement of 3 m or less. If this requirement was met, then C-band equipment would be adequate for use in orbit determination.

The FPS-16 radar came very close to meeting this requisite. The actual statistics have already been discussed. However, the results were not consistent on a pass-to-pass basis. The navigation difference went as high as 7.8 m in one case.

CONCLUSION

The standard errors in range based on C-band data were generally above 1 m, while those based on Doppler data were consistently below 1 m. Since the computation of the orbit of the GEOS-III satellite was performed with the goal of achieving maximum accuracy compatible with the 60-cm random error of the altimeter measurements, and since the more precise range measurements made with the geoceiver data yielded orbits to an accuracy of about 1.5 m (Reference 4), it was concluded that C-band radar data are not an adequate substitute for geoceiver data in this application.

However, the differences in precision are not significant and, in fact, can favor the C-band for many applications. Furthermore, detailed studies of the C-band data that have since been performed (Reference 5) show that increases in both precision and accuracy are achievable.

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